The Digital Energy Management of a Stand-Alone Hybrid System Photovoltaic-Wind

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Abstract — In this paper, a stand-alone hybrid energy system compound of photovoltaic panels (PV), wind turbine and battery storage is proposed to feed a continuous load. Three DC–DC converters (a boost, tow Buck/boost shunt) are used with the feedback voltage control for tracking the maximum power point of PV and regulating the voltage of the DC bus at the fixed value 311V. The main objective of this work is to insure the continuous supply to the load (1.5 kW), while supervising the output power from renewable energy system and the state of charge/discharge of the battery storage. In order to make in function the complete system under the optimal conditions we propose a simple and cost-effective digital control of the energy management (based on electronic switches and dump load). The proposed system is attractive because of its simplicity and its easiness of control. The results prove that the system can guarantee the high quality power to the load, even if the weather conditions are unavailable permanently. A complete description of the energy management strategy and the system control is proposed in this document. Orcad Pspice simulation results have shown the availability and reliability of the proposed hybrid system.

Keywords— hybrid System, photovoltaic System, Wind system, DC–DC Converter, Energy management.

I. INTRODUCTION

Currently, the production of domestic and industrial energy is based basically on traditional energy resources of fossil origins. This suggests that future progress of mankind will be impossible, because the energy is necessary for humanity and always will be, there is a huge correlation between lack of energy and poverty [1]–[2]. Other reason for reducing our dependence on fossil fuels is the growth of the global warming phenomena. Therefore, it is imperative to find and develop alternative energy sources to cover the energy demand of the current society while respecting the environment. Many scientific researchers were carried out in the sector of the unlimited energy sources as the wind and solar energy conversion. The Photovoltaic (PV) and the wind turbines are both the most promising energy sources due to the fact that they are free and bearable and more environmentally friendly. Today, Photovoltaic and wind generators are used in many applications such: water pumping, lighting, telecommunications and rural electrification. However, the major disadvantage of these renewable sources is their intermittent effect, i.e. risk of the non satisfaction of the load. This makes them unpredictable or even not very reliable to the eyes of some compared to the traditional electric energy [3]. This gap isn’t relating only to the energy performance of the system, but also the lifetime of the batteries will be limited and thus we throw them very early. In general, the independent use of the two energy resources could not provide a continuous supply to the load, due to the seasonal and periodic weather changes for autonomous systems [4]. At present, the combination of renewable sources, PV and Wind, offers an excellent solution to the problems caused by the stochastic nature of these sources, using the strengths of a source to overcome the weakness of the other. The use of different energy sources can further improve the system reliability and reduced the energy storage requirements, compared to systems with only one renewable energy source [5]. For some locations, the hybrid system PV&Wind for electrical production with a storage bank offers a very reliable source of power, which is adapted to electrical loads that require high reliability [6]–[7]. Consequently, the storage systems like batteries bank or super capacitors are very important in a hybrid system PV&Wind [6]. In this paper, a hybrid energy system combining wind, PV production systems and a batteries bank is presented to ensure continuous power to stand-alone load and to reduce fluctuations in the output power. The PV and wind power are used as main (primary) energy sources, while the batteries bank is used as energy source of help (secondary). To make in function the hybrid system under the optimal conditions, on the one hand, each system is used with its individual converter by controlling the three sources independently and, on the other hand, all sources must be coupled to a bus DC of constant voltage. The DC bus feeds the DC load, knowing that AC loads are fed by an inverter. Three DC–DC converters (A Boost converter, two Buck/Boost shunt) are used with the automatic voltage control (AVC), for tracking the maximum power point of PV and to maintain the voltage DC bus to the fixed value 311V, when the renewable energy sources and the batteries are connected. In order to reach a reliable power supply, a digital control energy management (DCEM) for the complete system is employed, based on a simple and reliable energy management strategy (EMS). The main objective of EMS is to reassure the continuous supply to the load (1.5 kW), while supervising the output power from renewable energy system and the state of charge/discharge of the battery storage. The proposed hybrid system is established in the Orcad/Pspice environment.

II. PROPOSED HYBRID SYSTEM

The fig 1 represents the topology of the hybrid energy system proposed consisting of two primary sources of energies (wind and PV array), a batteries bank, DC–DC converters, continues load, a dump load, a digital control
energy management and a control system. The Energy sources are connected in parallel to a common DC bus through their various DC-DC converters. Each source has its individual control type feedback loop voltage (FLV). Regulating the voltage on the DC bus (Vbus) is implemented by the wind system and the batteries bank. Thus, the DC bus is regulated to a constant voltage value (311V). Continuous load is connected to the DC bus line. In order to manage the energy flow with precision, a digital control energy management and a dump load are introduced. The diodes D1 and D2 (MUR8100) [25] allow only unidirectional current source to DC bus line, thus preventing each source from acting like a load on each other. Therefore, in the failure case of any energy sources, the respective diode will automatically disconnect that source from the system.

Fig.1: Hybrid Energy System Configuration.

A. Photovoltaic System

The Photovoltaic system becomes increasingly important as renewable energy source, because it offers many advantages such as: no fuel spawning, non-polluting, and requiring little maintenance. The PV module Mitsubishi UD180MF5 commercial was selected in this study [24]. The table I present the characteristics of the PV module given by the manufacturer at the 25°C nominal temperature. The photovoltaic system (fig.2) implanted in the environment ORCAD/PSPICE generally includes: a Photovoltaic array, a Boost, and the AVC. In this system, the photovoltaic panel is a group of 12 modules six connected in series and tow in parallel to produce a maximum power of 2.1kW at irradiance conditions of 1000W/m².

Table.I: Electrical Characteristics of the Mitsubishi UD180MF5 PV module [24].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cells</td>
<td>50 in series</td>
</tr>
<tr>
<td>Maximum power rating</td>
<td>180Wp</td>
</tr>
<tr>
<td>Open circuit voltage (Voc)</td>
<td>30.4V</td>
</tr>
<tr>
<td>Short circuit current (Isc)</td>
<td>8.03A</td>
</tr>
<tr>
<td>Maximum power voltage (Vmp)</td>
<td>24.2V</td>
</tr>
<tr>
<td>Maximum power current (Imp)</td>
<td>7.45A</td>
</tr>
</tbody>
</table>

Fig.2: Chain Photovoltaic Conversion With Converter Controlled by Voltage Control:

The model of the PV cell [8]-[9] and the above data were used in the simulations to obtain the output of the solar panel characteristics. The curves of the figs 3 and 4 show the characteristics of the PV module at different intensities of solar radiation. I-V and P-V characteristics are strongly influenced by weather conditions, especially radiation and PV module temperature. For a given temperature and radiation, the P-V characteristic reaches a maximum. Therefore, it is imperative to carry out a Maximum power point tracker (MPPT) of the PV. Several MPPT techniques of photovoltaic systems have been proposed as the perturbation and observation (P&O) [10]-[11]-[12], incremental conductance (IncCond) [13]-[14], the method of short circuit (Isc) [15], and the method of open circuit voltage (Voc) [16]. In this paper the technique used is based on the automatic voltage control of the PV generator [17]. Indeed, the terminal voltage of the PV generator (Vpv) varies slightly from the illumination around the maximum power. This is why we operate the PV generator under a voltage of 145V this could be ensured by AVC (fig 9) acting on the duty cycle \( \alpha \) of the signal controlling the interrupter of the converter (equation 1) [17]. This was chosen because of its simplicity of implementation and lower cost.

\[
V_{out} = \frac{V_{pv}}{1 - \alpha} \tag{-1-}
\]

Where the Vpv (V) is the terminal voltage of the photovoltaic generator, and Vout (V) is the output voltage of the converter.

Fig.3: P-V Characteristics of PV Modules
B. Wind System

The windmill uses the wind kinetic energy to drive the shaft of his rotor. This one is then converted into mechanical energy which is transformed after into electrical energy. In this work we opt for self-excited induction generators (SEIG) [17]-[18]-[19].

The electric conversion chain (fig 5) implanted in the Orcad Pspice environment generally contain:

- The machine SEIG which has the following characteristics: $P=1.5kW$, $f=50Hz$, $V=220/380V$, $I_s = 4.4A$, $p = 2$, $R_s = 5.51\Omega$, $R_r=2.24\Omega$, $X_r = 6.9\Omega$, $X_m = 38.81\Omega$ [17]-[18]-[20].
- A rectifier to six diodes for converting the AC voltage into DC voltage.
- A LC filter consisting of an L inductor in series with a C capacitor.
- An energy converter type: Buck/Boost shunts to maintain the output voltage to $311V$.
- The AVC allows regulating the desired voltage ($311V$) at the DC bus terminals when there is a variation of the wind speed [17]-[18]-[20]. Its principal regulation is based on the automatic variation of the duty cycle $\alpha$ at the proper value to obtain the desired voltage at the DC bus.

C. Battery

Most batteries used in the hybrid systems are lead-acid type. They have a long lifetime, a storage capacity and higher efficiency. What makes their use preferable compared with the other batteries types. The batteries are generally used to store electrical energy, setting the system voltage, and provide energy in case of bad climatic conditions (low wind, low radiation). Many battery models exist [21]-[22]. The most popular is the Thevenin equivalent circuit, which is illustrated in fig 6 [23]. The circuit consists of a $C_b$ capacitor, an internal resistance is represented by two series resistors ($R_{b1}$ and $R_{b2}$) and a parallel resistance ($R_{bp}$) to the main capacitor $C_{bp}$. The $C_{bp}$ capacitor represents the electrochemical energy of the battery capacity; its value is obtained from the General expression (2) of energy in a capacitor [23]. The $R_{bp}$ resistance represents the self-discharge of the battery.

$$C_{bp} = \frac{2E_b}{(V_{max}^2 - V_{min}^2)}$$  

Where the $E_b$ is Battery energy ($1000 Ah$) and the $V_{max}$,$V_{min}$ : Maximum and minimum voltage supported by the capacitor $C_{bp}$ ($V_{max}=70V$ et $V_{min}=55V$).

D. The Automatic Voltage Control

In fig 8, we represented the diagram of the automatic voltage control (AVC) [17]-[20]. This command is characterized by ease of implementation and low cost [17]. In addition, it could operate at high switching frequencies (greater than 0.1 MHz). This AVC uses the voltage at the output to search the optimal voltage be desired. The
implementation of this command involves only analog components. The dynamics of the system depends only on the delay time of the analogue components which is generally very low. The Different blocks of this command are:

- A differential amplifier
- Inverting amplifier
- A proportional–integral (PI) controller
- The integrator (RC) time constant, its role is to generate the reference voltage ($V_r$).
- LM3319 comparator: the voltage $V_r$ is compared with the saw tooth signal for generating at the output of the comparator a signal modulated in pulse width and frequency of 10 kHz. This signal is supplied to the inverter MOSFET through the driver IR2111.

![Fig.8: Synoptic Diagram of the AVC [17]](image)

### III. ENERGY MANAGEMENT STRATEGY

In order to manage the energy flow of the hybrid system, we proposed a digital control of the energy management (DCEM) for the complete system, based on a simple energy management strategy (EMS). Indeed, the PV and the wind turbine works together to respond the load demand. When the renewable energy sources are abundant (after satisfying the load demand) and the batteries bank fully charged (state1), the energy excess will be dissipated in a dump load. On the contrary, when the energy produced by the PV/Wind sources is insufficient to feed the load (1.5kW), the battery will be delivered the energy needed to help the PV/wind to cover the load demand until the storage is exhausted (state 0). When the battery is exhausted, the battery charge becomes a priority, so all the energy produced by the PV &Wind must be transferred to the battery until it is fully charged (State1).

### IV. DIGITAL CONTROL ENERGY MANAGEMENT

The fig 9 shows the DCEM proposed in this document; which is characterized by its simplicity of realization and its lower cost. The DCEM uses a power sensor, and a hysteresis comparator determines the state of charge (1) and discharge (0) of the Battery. The DCEM is usually composed by NAND, AND, NOR, EXCLUSIVE OR functions of the CMOS 4000B series. This latter has several advantages namely, low power dissipation (10nW), wide operating voltage range (3 to 15V), wide operating temperature range (-40 to 85 °C), a higher operating speed and an excellent noise immunity.

![Fig.9: Digital Control Energy Management (DCEM)]](image)

### V. SIMULATION RESULTS

In order to prove the reliability and the performances of the proposed hybrid system, we simulated the complete system with the Orcad-Pspice software. The hybrid system is sized to feed a DC load of 1.5kW. The load is simulated as a constant resistive load (60 Ω) connected to the fixed voltage DC bus line (311V). The first simulation of the hybrid system is achieved by varying the radiation from 500W/m² to 1000W/m², the wind speed from 0rad/s to 320rad/s and the battery state from 1 (full load) to 0 (exhausted). The figs.10 (a)-10 (c) shows the output power variation of the two sources (PV & wind), plus the total power generated by the hybrid system. The power delivered and stored by the battery bank is shown in fig 11. The load power (1.5kW) and the battery current charging/discharging are illustrated in the figs 12 and 13. Indeed, until t=1.5s, a part of the power required by the load (fig 12) is ensured by the batteries bank (fig 11) and the I_bat current is positive (battery charging fig13). At time t=1.5s, the radiation (fig 10 (a)) and the wind speed change (fig 10 (b)), and the battery takes the state 0, the power supplied by the hybrid system PV/wind (fig10.c) is completely sent to the battery bank (fig11) and the I_bat current becomes negative (battery charging fig13). Consequently, the power sent to the load becomes zero as shown in the fig.12.

![Fig 10.(a): The Output Power of the PV]](image)
The second simulation was carried out for a hybrid system to provide a constant power and to change the battery state from 0 (exhausted) to 1 (full load). The results of this test are illustrated in the figs 14 (a)-14 (b) and figs 15 (a)-15(b). The figs 14 (a)-14(b) shows the power produced by the wind and PVs, and the total output power of the hybrid system (HS) is sent to the battery bank, knowing that the figs 15 (a)-15(b) illustrates the power delivered by the HS to the resistive load and the power dissipated in a dump load. The voltage and the current of the battery which was in charge are shown in the fig 16. As we can see, until the moment t=1.52s, the power provided by the renewable sources is fully transferred to the battery (fig14.(b)) and I_bat current is negative (the battery charging state 0 fig16.(a)), thus the load power is zero (fig15.(a)). As at the moment t=1.52s the battery is fully charged (state 1 fig16.(b)), and the surplus power produced by the HS (fig14.(b)) is delivered to the dump load (fig 15.(b)).
VI. CONCLUSION

This article describes a digital control of the energy management for a stand-alone hybrid system, which is based on a simple and reliable energy management strategy. The hybrid system generally includes a PV panel, a wind and a bank of lead-acid batteries, which are connected to the constant voltage DC bus across the power DC-converter, these latter are controlled by an automatic voltage control. The simulation results show that the DCEM can manage the power flow produced by the hybrid system according to the State of the battery and the power requested by the load. These results confirm the feasibility and the reliability of the system suggested in this document.

REFERENCES


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SEDDIK Mohammed received Master of electronics and communication system from Faculty of Science, Mohamed I University, Oujda, Morocco in 2008. He is currently pursuing his doctorate in Laboratory of Electrical Engineering and Maintenance at Higher Institute of Technology, Mohamed I University, Oujda, Morocco. His current research interests include Hybrid system Combining Wind and Photovoltaic.

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